Assembly Language for x86 Processors
7th Edition

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Chapter 6: Conditional Processing

Slides prepared by the author

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Chapter Overview

- **Boolean and Comparison Instructions**
- Conditional Jumps
- Conditional Loop Instructions
- Conditional Structures
- Application: Finite-State Machines
- Conditional Control Flow Directives

Boolean and Comparison Instructions

- CPU Status Flags
- AND Instruction
- OR Instruction
- XOR Instruction
- NOT Instruction
- Applications
- TEST Instruction
- CMP Instruction

Status Flags - Review

- The Zero flag is set when the result of an operation equals zero.
- The Carry flag is set when an instruction generates a result that is too large (or too small) for the destination operand.
- The Sign flag is set if the destination operand is negative, and it is clear if the destination operand is positive.
- The Overflow flag is set when an instruction generates an invalid signed result (bit 7 carry is XORed with bit 6 Carry).
- The Parity flag is set when an instruction generates an even number of 1 bits in the low byte of the destination operand.
- The Auxiliary Carry flag is set when an operation produces a carry out from bit 3 to bit 4

AND Instruction

- Performs a Boolean AND operation between each pair of matching bits in two operands
- Syntax:

  AND *destination, source*

  (same operand types as MOV)

```
               0 0 1 1 1 0 1 1
        AND    0 0 0 0 1 1 1 1
             -------------------
cleared ---   0 0 0 0 | 1 0 1 1   --- unchanged
```

AND

x	y	$x \wedge y$
0	0	0
0	1	0
1	0	0
1	1	1

OR Instruction

- Performs a Boolean OR operation between each pair of matching bits in two operands
- Syntax:

```
OR destination, source
```

```
                 0 0 1 1 1 0 1 1
            OR   0 0 0 0 1 1 1 1
                 ---------------
unchanged ------ 0 0 1 1 1 1 1 1 ------ set
```

OR

x	y	x ∨ y
0	0	0
0	1	1
1	0	1
1	1	1

XOR Instruction

- Performs a Boolean exclusive-OR operation between each pair of matching bits in two operands
- Syntax:

```
XOR destination, source
```

```
           0 0 1 1 1 0 1 1
XOR        0 0 0 0 1 1 1 1
           ---------------
unchanged  0 0 1 1|0 1 0 0  inverted
```

XOR

x	y	$x \oplus y$
0	0	0
0	1	1
1	0	1
1	1	0

XOR is a useful way to toggle (invert) the bits in an operand.

NOT Instruction

- Performs a Boolean NOT operation on a single destination operand
- Syntax:

  NOT *destination*

```
NOT   0 0 1 1 1 0 1 1
      ---------------
      1 1 0 0 0 1 0 0 ——— inverted
```

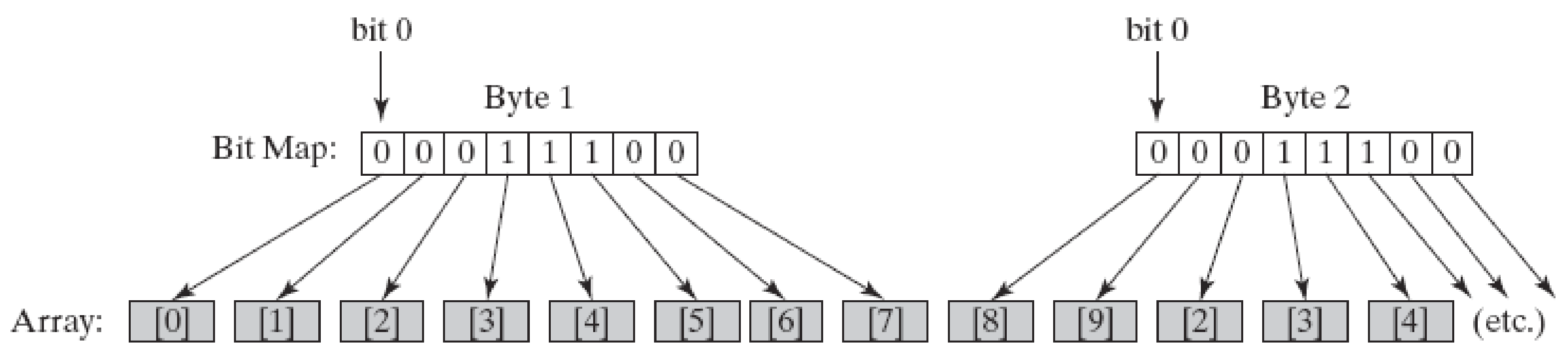
NOT

X	¬X
F	T
T	F

Bit-Mapped Sets

- Binary bits indicate set membership
- Efficient use of storage
- Also known as *bit vectors*

FIGURE 6–1 Mapping Binary Bits to an Array.



Bit-Mapped Set Operations

- Set Complement

```
mov eax,SetX
not eax
```

- Set Intersection

```
mov eax,setX
and eax,setY
```

- Set Union

```
mov eax,setX
or  eax,setY
```

Applications (1 of 5)

- Task: Convert the character in AL to upper case.
- Solution: Use the AND instruction to clear bit 5.

```
mov al,'a'                ; AL = 01100001b
and al,11011111b          ; AL = 01000001b
```

Applications (2 of 5)

- Task: Convert a binary decimal byte into its equivalent ASCII decimal digit.
- Solution: Use the OR instruction to set bits 4 and 5.

```
mov al,6                    ; AL = 00000110b
or  al,00110000b            ; AL = 00110110b
```

The ASCII digit '6' = 00110110b

Applications (3 of 5)

- Task: Turn on the keyboard CapsLock key
- Solution: Use the OR instruction to set bit 6 in the keyboard flag byte at 0040:0017h in the BIOS data area.

```
mov ax,40h                       ; BIOS segment
mov ds,ax
mov bx,17h                       ; keyboard flag byte
or BYTE PTR [bx],01000000b       ; CapsLock on
```

This code only runs in Real-address mode, and it does not work under Windows NT, 2000, or XP.

Applications (4 of 5)

- Task: Jump to a label if an integer is even.
- Solution: AND the lowest bit with a 1. If the result is Zero, the number was even.

```
mov ax,wordVal
and ax,1                ; low bit set?
jz  EvenValue           ; jump if Zero flag set
```

JZ (jump if Zero) is covered in Section 6.3.

Your turn: Write code that jumps to a label if an integer is negative.

Applications (5 of 5)

- Task: Jump to a label if the value in AL is not zero.
- Solution: OR the byte with itself, then use the JNZ (jump if not zero) instruction.

```
or  al,al
jnz IsNotZero             ; jump if not zero
```

ORing any number with itself does not change its value.

TEST Instruction

- Performs a nondestructive AND operation between each pair of matching bits in two operands
- No operands are modified, but the Zero flag is affected.
- Example: jump to a label if either bit 0 or bit 1 in AL is set.

```
test al,00000011b
jnz  ValueFound
```

- Example: jump to a label if neither bit 0 nor bit 1 in AL is set.

```
test al,00000011b
jz   ValueNotFound
```

CMP Instruction (1 of 3)

- Compares the destination operand to the source operand
  - Nondestructive subtraction of source from destination (destination operand is not changed)
- Syntax: CMP *destination, source*
- Example: destination == source

```
mov al,5
cmp al,5                ; Zero flag set
```

- Example: destination < source

```
mov al,4
cmp al,5                ; Carry flag set
```

CMP Instruction (2 of 3)

- Example: destination > source

```
mov al,6
cmp al,5                    ; ZF = 0, CF = 0
```

(both the Zero and Carry flags are clear)

CMP Instruction (3 of 3)

The comparisons shown here are performed with signed integers.

- Example: destination > source

```
mov al,5
cmp al,-2            ; Sign flag == Overflow flag
```

- Example: destination < source

```
mov al,-1
cmp al,5             ; Sign flag != Overflow flag
```

Boolean Instructions in 64-Bit Mode

- 64-bit boolean instructions, for the most part, work the same as 32-bit instructions
- If the source operand is a constant whose size is less than 32 bits and the destination is the lower part of a 64-bit register or memory operand, all bits in the destination operand are affected
- When the source is a 32-bit constant or register, only the lower 32 bits of the destination operand are affected

What's Next

- Boolean and Comparison Instructions
- **Conditional Jumps**
- Conditional Loop Instructions
- Conditional Structures
- Application: Finite-State Machines
- Conditional Control Flow Directives

Conditional Jumps

- Jumps Based On . . .
  - Specific flags
  - Equality
  - Unsigned comparisons
  - Signed Comparisons
- Applications
- Encrypting a String
- Bit Test (BT) Instruction

J*cond* Instruction

- A conditional jump instruction branches to a label when specific register or flag conditions are met

- Specific jumps:

  JB, JC - jump to a label if the Carry flag is set

  JE, JZ - jump to a label if the Zero flag is set

  JS - jump to a label if the Sign flag is set

  JNE, JNZ - jump to a label if the Zero flag is clear

  JECXZ - jump to a label if ECX = 0

J*cond* Ranges

- Prior to the 386:
  - jump must be within –128 to +127 bytes from current location counter
- x86 processors:
  - 32-bit offset permits jump anywhere in memory

Jumps Based on Specific Flags

Mnemonic	Description	Flags
JZ	Jump if zero	ZF = 1
JNZ	Jump if not zero	ZF = 0
JC	Jump if carry	CF = 1
JNC	Jump if not carry	CF = 0
JO	Jump if overflow	OF = 1
JNO	Jump if not overflow	OF = 0
JS	Jump if signed	SF = 1
JNS	Jump if not signed	SF = 0
JP	Jump if parity (even)	PF = 1
JNP	Jump if not parity (odd)	PF = 0

Jumps Based on Equality

Mnemonic	Description
JE	Jump if equal (*leftOp* = *rightOp*)
JNE	Jump if not equal (*leftOp* ≠ *rightOp*)
JCXZ	Jump if CX = 0
JECXZ	Jump if ECX = 0

Jumps Based on Unsigned Comparisons

Mnemonic	Description
JA	Jump if above (if *leftOp* > *rightOp*)
JNBE	Jump if not below or equal (same as JA)
JAE	Jump if above or equal (if *leftOp* >= *rightOp*)
JNB	Jump if not below (same as JAE)
JB	Jump if below (if *leftOp* < *rightOp*)
JNAE	Jump if not above or equal (same as JB)
JBE	Jump if below or equal (if *leftOp* <= *rightOp*)
JNA	Jump if not above (same as JBE)

Jumps Based on Signed Comparisons

Mnemonic	Description
JG	Jump if greater (if *leftOp* > *rightOp*)
JNLE	Jump if not less than or equal (same as JG)
JGE	Jump if greater than or equal (if *leftOp* >= *rightOp*)
JNL	Jump if not less (same as JGE)
JL	Jump if less (if *leftOp* < *rightOp*)
JNGE	Jump if not greater than or equal (same as JL)
JLE	Jump if less than or equal (if *leftOp* <= *rightOp*)
JNG	Jump if not greater (same as JLE)

Applications (1 of 5)

- Task: Jump to a label if unsigned EAX is greater than EBX
- Solution: Use CMP, followed by JA

```
cmp eax,ebx
ja  Larger
```

- Task: Jump to a label if signed EAX is greater than EBX
- Solution: Use CMP, followed by JG

```
cmp eax,ebx
jg  Greater
```

Applications (2 of 5)

- Jump to label L1 if unsigned EAX is less than or equal to Val1

```
cmp eax,Val1
jbe L1              ; below or equal
```

- Jump to label L1 if signed EAX is less than or equal to Val1

```
cmp eax,Val1
jle L1
```

Applications (3 of 5)

- Compare unsigned AX to BX, and copy the larger of the two into a variable named Large

```
    mov Large,bx
    cmp ax,bx
    jna Next
    mov Large,ax
Next:
```

- Compare signed AX to BX, and copy the smaller of the two into a variable named Small

```
    mov Small,ax
    cmp bx,ax
    jnl Next
    mov Small,bx
Next:
```

Applications (4 of 5)

- Jump to label L1 if the memory word pointed to by ESI equals Zero

```
cmp WORD PTR [esi],0
je  L1
```

- Jump to label L2 if the doubleword in memory pointed to by EDI is even

```
test DWORD PTR [edi],1
jz   L2
```

Applications (5 of 5)

- Task: Jump to label L1 if bits 0, 1, and 3 in AL are all set.
- Solution: Clear all bits except bits 0, 1,and 3. Then compare the result with 00001011 binary.

```
and al,00001011b        ; clear unwanted bits
cmp al,00001011b        ; check remaining bits
je  L1                  ; all set? jump to L1
```

Your turn . . .

- Write code that jumps to label L1 if either bit 4, 5, or 6 is set in the BL register.
- Write code that jumps to label L1 if bits 4, 5, and 6 are all set in the BL register.
- Write code that jumps to label L2 if AL has even parity.
- Write code that jumps to label L3 if EAX is negative.
- Write code that jumps to label L4 if the expression (EBX – ECX) is greater than zero.

Encrypting a String

The following loop uses the XOR instruction to transform every character in a string into a new value.

```
KEY = 239                          ; can be any byte value
BUFMAX = 128
.data
buffer  BYTE BUFMAX+1 DUP(0)
bufSize DWORD BUFMAX

.code
   mov ecx,bufSize                 ; loop counter
   mov esi,0                       ; index 0 in buffer
L1:
   xor buffer[esi],KEY             ; translate a byte
   inc esi                         ; point to next byte
   loop L1
```

String Encryption Program

- Tasks:
  - Input a message (string) from the user
  - Encrypt the message
  - Display the encrypted message
  - Decrypt the message
  - Display the decrypted message

View the Encrypt.asm program's source code. Sample output:

```
Enter the plain text: Attack at dawn.

Cipher text: «¢¢Äîä-Ä¢-iÄÿü-Gs

Decrypted: Attack at dawn.
```

BT (Bit Test) Instruction

- Copies bit *n* from an operand into the Carry flag
- Syntax: BT *bitBase, n*
  - bitBase may be *r/m16* or *r/m32*
  - n may be *r16, r32*, or *imm8*
- Example: jump to label L1 if bit 9 is set in the AX register:

```
bt AX,9          ; CF = bit 9
jc L1            ; jump if Carry
```

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Conditional Loop Instructions

- LOOPZ and LOOPE
- LOOPNZ and LOOPNE

LOOPZ and LOOPE

- Syntax:

  LOOPE *destination*

  LOOPZ *destination*
- Logic:
  - ECX $\leftarrow$ ECX – 1
  - if ECX > 0 and ZF=1, jump to *destination*
- Useful when scanning an array for the first element that does not match a given value.

In 32-bit mode, ECX is the loop counter register. In 16-bit real-address mode, CX is the counter, and in 64-bit mode, RCX is the counter.

LOOPNZ and LOOPNE

- LOOPNZ (LOOPNE) is a conditional loop instruction
- Syntax:

  LOOPNZ *destination*

  LOOPNE *destination*
- Logic:
  - ECX ← ECX – 1;
  - if ECX > 0 and ZF=0, jump to *destination*
- Useful when scanning an array for the first element that matches a given value.

LOOPNZ Example

The following code finds the first positive value in an array:

```
.data
array SWORD -3,-6,-1,-10,10,30,40,4
sentinel SWORD 0
.code
    mov esi,OFFSET array
    mov ecx,LENGTHOF array
next:
    test WORD PTR [esi],8000h  ; test sign bit
    pushfd                     ; push flags on stack
    add esi,TYPE array
    popfd                      ; pop flags from stack
    loopnz next                ; continue loop
    jnz quit                   ; none found
    sub esi,TYPE array         ; ESI points to value
quit:
```

Your turn . . .

Locate the first nonzero value in the array. If none is found, let ESI point to the sentinel value:

```
.data
array SWORD 50 DUP(?)
sentinel SWORD 0FFFFh
.code
    mov esi,OFFSET array
    mov ecx,LENGTHOF array
L1: cmp WORD PTR [esi],0          ; check for zero

     (fill in your code here)

quit:
```

. . . (solution)

```
.data
array SWORD 50 DUP(?)
sentinel SWORD 0FFFFh
.code
    mov esi,OFFSET array
    mov ecx,LENGTHOF array
L1: cmp WORD PTR [esi],0         ; check for zero
    pushfd                       ; push flags on stack
    add esi,TYPE array
    popfd                        ; pop flags from stack
    loope L1                     ; continue loop
    jz quit                      ; none found
    sub esi,TYPE array           ; ESI points to value
quit:
```

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- Boolean and Comparison Instructions
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Conditional Structures

- Block-Structured IF Statements
- Compound Expressions with AND
- Compound Expressions with OR
- WHILE Loops
- Table-Driven Selection

Block-Structured IF Statements

Assembly language programmers can easily translate logical statements written in C++/Java into assembly language. For example:

```
if( op1 == op2 )
  X = 1;
else
  X = 2;
```

```
    mov eax,op1
    cmp eax,op2
    jne L1
    mov X,1
    jmp L2
L1: mov X,2
L2:
```

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if( ebx <= ecx )
{
  eax = 5;
  edx = 6;
}
```

```
    cmp ebx,ecx
    ja  next
    mov eax,5
    mov edx,6
next:
```

(There are multiple correct solutions to this problem.)

Your turn . . .

Implement the following pseudocode in assembly language. All values are 32-bit signed integers:

```
if( var1 <= var2 )
  var3 = 10;
else
{
  var3 = 6;
  var4 = 7;
}
```

```
    mov eax,var1
    cmp eax,var2
    jle L1
    mov var3,6
    mov var4,7
    jmp L2
L1: mov var3,10
L2:
```

(There are multiple correct solutions to this problem.)

Compound Expression with AND (1 of 3)

- When implementing the logical AND operator, consider that HLLs use short-circuit evaluation
- In the following example, if the first expression is false, the second expression is skipped:

```
if (al > bl) AND (bl > cl)
  X = 1;
```

Compound Expression with AND (2 of 3)

```
if (al > bl) AND (bl > cl)
   X = 1;
```

This is one possible implementation . . .

```
    cmp al,bl              ; first expression...
    ja  L1
    jmp next
L1:
    cmp bl,cl              ; second expression...
    ja  L2
    jmp next
L2:                        ; both are true
    mov X,1                ; set X to 1
next:
```

Compound Expression with AND (3 of 3)

```
if (al > bl) AND (bl > cl)
  X = 1;
```

But the following implementation uses 29% less code by reversing the first relational operator. We allow the program to "fall through" to the second expression:

```
    cmp al,bl              ; first expression...
    jbe next               ; quit if false
    cmp bl,cl              ; second expression...
    jbe next               ; quit if false
    mov X,1                ; both are true
next:
```

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if( ebx <= ecx
    && ecx > edx )
{
  eax = 5;
  edx = 6;
}
```

```
    cmp ebx,ecx
    ja  next
    cmp ecx,edx
    jbe next
    mov eax,5
    mov edx,6
next:
```

(There are multiple correct solutions to this problem.)

Compound Expression with OR (1 of 2)

- When implementing the logical OR operator, consider that HLLs use short-circuit evaluation
- In the following example, if the first expression is true, the second expression is skipped:

```
if (al > bl) OR (bl > cl)
  X = 1;
```

Compound Expression with OR (2 of 2)

```
if (al > bl) OR (bl > cl)
  X = 1;
```

We can use "fall-through" logic to keep the code as short as possible:

```
    cmp al,bl             ; is AL > BL?
    ja  L1                ; yes
    cmp bl,cl             ; no: is BL > CL?
    jbe next              ; no: skip next statement
L1: mov X,1               ; set X to 1
next:
```

WHILE Loops

A WHILE loop is really an IF statement followed by the body of the loop, followed by an unconditional jump to the top of the loop. Consider the following example:

```
while( eax < ebx)
    eax = eax + 1;
```

This is a possible implementation:

```
top:cmp eax,ebx          ; check loop condition
    jae next             ; false? exit loop
    inc eax              ; body of loop
    jmp top              ; repeat the loop
next:
```

Your turn . . .

Implement the following loop, using unsigned 32-bit integers:

```
while( ebx <= val1)
{
    ebx = ebx + 5;
    val1 = val1 - 1
}
```

```
top: cmp ebx,val1              ; check loop condition
     ja  next                  ; false? exit loop
     add ebx,5                 ; body of loop
     dec val1
     jmp top                   ; repeat the loop
next:
```

Table-Driven Selection (1 of 4)

- Table-driven selection uses a table lookup to replace a multiway selection structure
- Create a table containing lookup values and the offsets of labels or procedures
- Use a loop to search the table
- Suited to a large number of comparisons

Table-Driven Selection (2 of 4)

Step 1: create a table containing lookup values and procedure offsets:

```
.data
CaseTable BYTE 'A'                ; lookup value
    DWORD Process_A               ; address of procedure
    EntrySize = ($ - CaseTable)
    BYTE 'B'
    DWORD Process_B
    BYTE 'C'
    DWORD Process_C
    BYTE 'D'
    DWORD Process_D

NumberOfEntries = ($ - CaseTable) / EntrySize
```

Table-Driven Selection (3 of 4)

Table of Procedure Offsets:

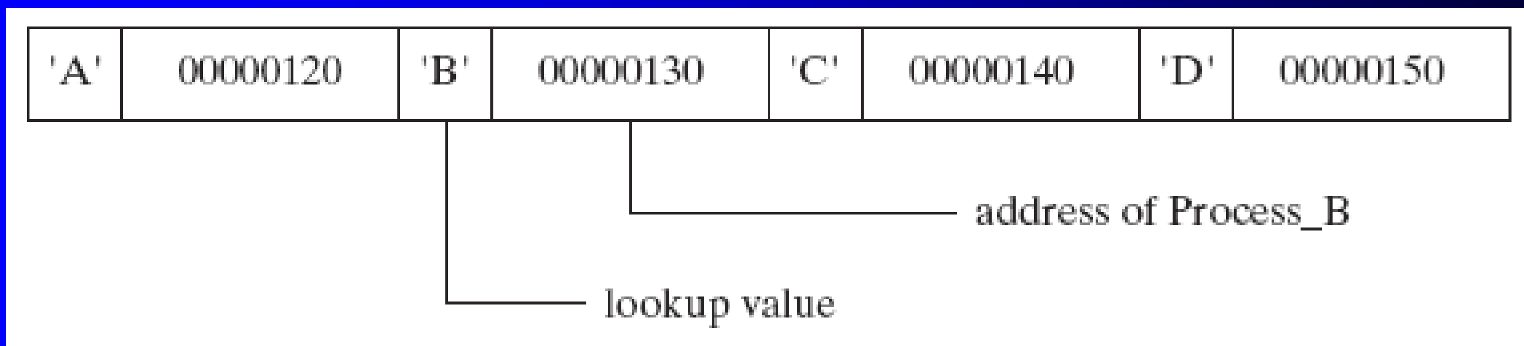


Table-Driven Selection (4 of 4)

Step 2: Use a loop to search the table. When a match is found, call the procedure offset stored in the current table entry:

```
    mov ebx,OFFSET CaseTable        ; point EBX to the table
    mov ecx,NumberOfEntries         ; loop counter

L1: cmp al,[ebx]                    ; match found?
    jne L2                          ; no: continue
    call NEAR PTR [ebx + 1]         ; yes: call the procedure
    call WriteString                ; display message
    call Crlf
    jmp L3                          ; and exit the loop
L2: add ebx,EntrySize               ; point to next entry
    loop L1                         ; repeat until ECX = 0

L3:
```

required for procedure pointers

What's Next

- Boolean and Comparison Instructions
- Conditional Jumps
- Conditional Loop Instructions
- Conditional Structures
- **Application: Finite-State Machines**
- Conditional Control Flow Directives

Application: Finite-State Machines

- A finite-state machine (FSM) is a graph structure that changes state based on some input. Also called a state-transition diagram.
- We use a graph to represent an FSM, with squares or circles called nodes, and lines with arrows between the circles called edges.

Application: Finite-State Machines

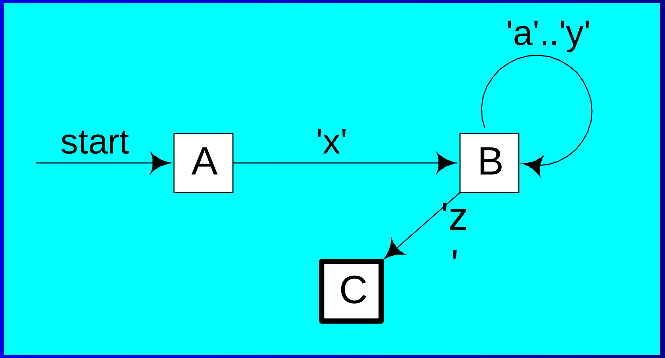
- A FSM is a specific instance of a more general structure called a directed graph.
- Three basic states, represented by nodes:
  - Start state
  - Terminal state(s)
  - Nonterminal state(s)

Finite-State Machine

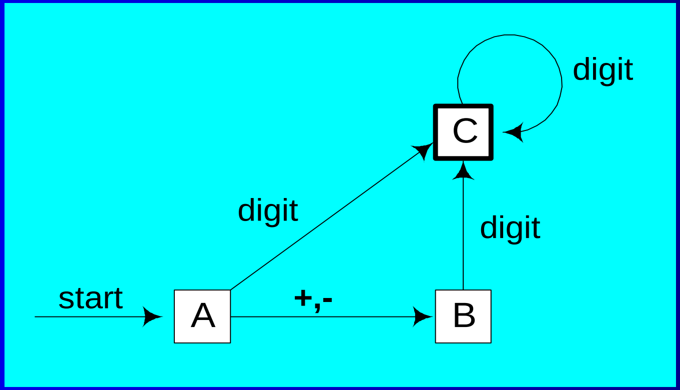
- Accepts any sequence of symbols that puts it into an accepting (final) state
- Can be used to recognize, or validate a sequence of characters that is governed by language rules (called a regular expression)
- Advantages:
  - Provides visual tracking of program's flow of control
  - Easy to modify
  - Easily implemented in assembly language

Finite-State Machine Examples

- FSM that recognizes strings beginning with 'x', followed by letters 'a'..'y', ending with 'z':

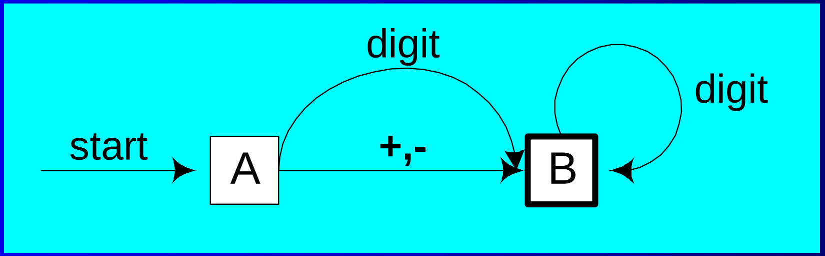


- FSM that recognizes signed integers:



Your Turn . . .

- Explain why the following FSM does not work as well for signed integers as the one shown on the previous slide:



Implementing an FSM

The following is code from State A in the Integer FSM:

```
StateA:
    call Getnext              ; read next char into AL
    cmp al,'+'                ; leading + sign?
    je StateB                 ; go to State B
    cmp al,'-'                ; leading - sign?
    je StateB                 ; go to State B
    call IsDigit              ; ZF = 1 if AL = digit
    jz StateC                 ; go to State C
    call DisplayErrorMsg      ; invalid input found
    jmp Quit
```

View the [Finite.asm source code].

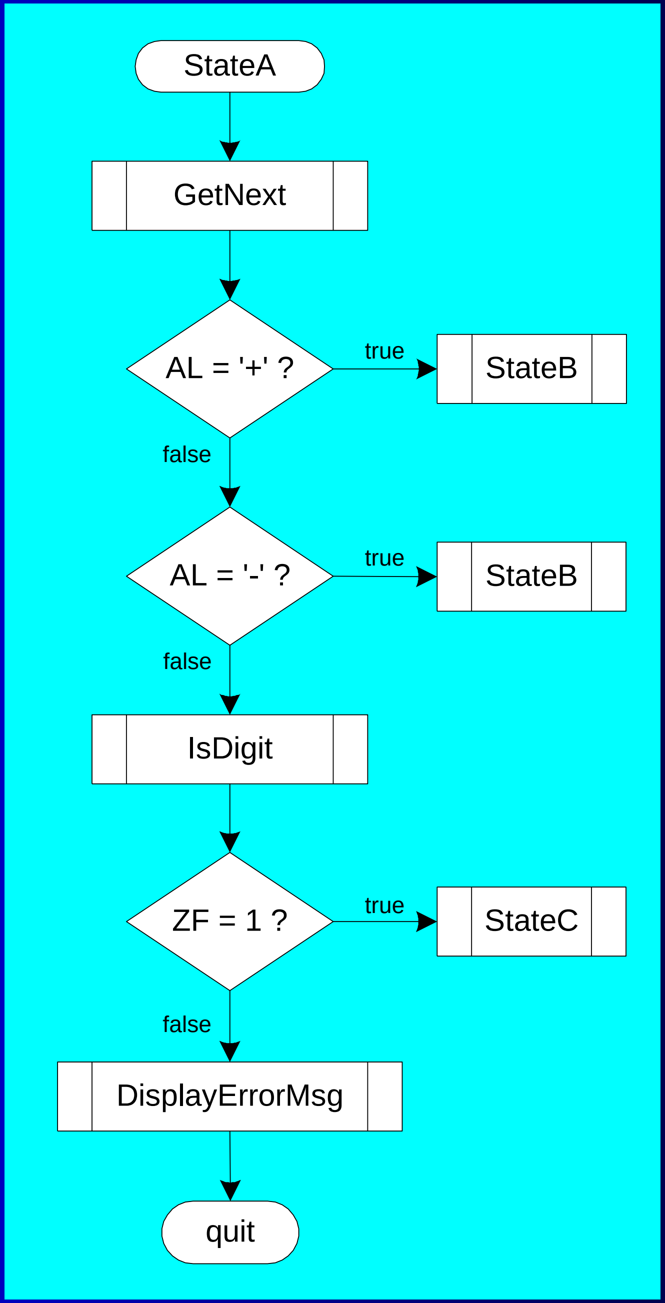
IsDigit Procedure

Receives a character in AL. Sets the Zero flag if the character is a decimal digit.

```
IsDigit PROC
     cmp   al,'0'           ; ZF = 0
     jb    ID1
     cmp   al,'9'           ; ZF = 0
     ja    ID1
     test  ax,0             ; ZF = 1
ID1: ret
IsDigit ENDP
```

Flowchart of State A

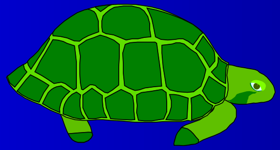
State A accepts a plus or minus sign, or a decimal digit.



Irvine, Kip R. Assembly Language for x86 Processors 7/e, 2015.

Your Turn . . .

- Draw a FSM diagram for hexadecimal integer constant that conforms to MASM syntax.
- Draw a flowchart for one of the states in your FSM.
- Implement your FSM in assembly language. Let the user input a hexadecimal constant from the keyboard.



4C 6F 70 70 75 75 6E